The Influence of New and Modernized GNSS on Positioning within RTK Networks

Gerhard Wübbena

Geo++® GmbH
30827 Garbsen
Germany
www.geopp.com

Outline

- New GNSS and Modernization
- Satellite Availability
- New Signals and Ambiguity Resolution
- Simulations
- Do we still need RTK Networks ?
- Challenges for Network RTK Software
- Summary

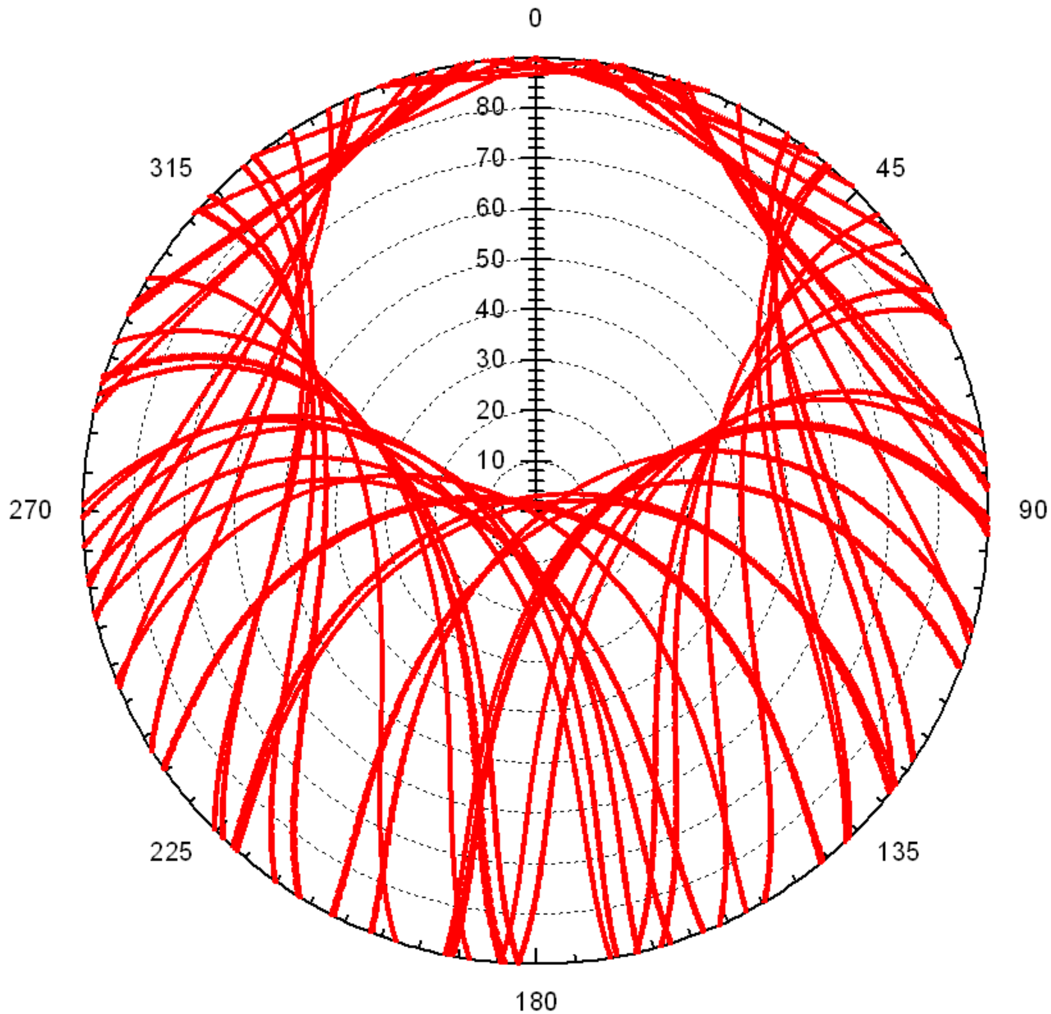
New GNSS and Modernization

- GPS will provide new (civil) signals (L2C, L5, L1c)
- GLONASS will have „Full Constellation“ in 2007/2008
- Galileo will be operational in 2011 ?
- Galileo will provide up to 5 frequencies with different signals
- All together more than 75 GNSS satellites will be available

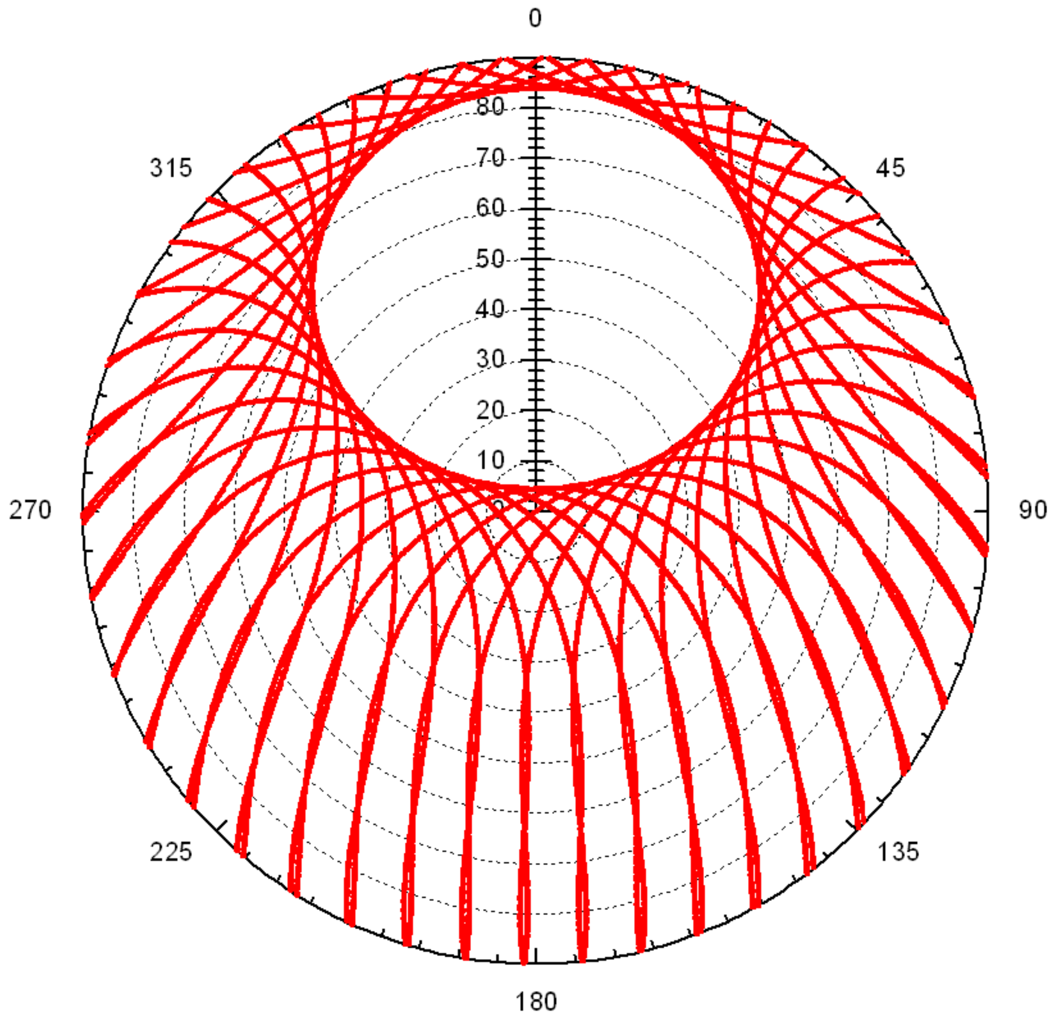
Satellite Availability

- Satellite Visibility Plots for Hannover, June 14, 2006 using
  - Current GPS Almanach
  - Galileo Constellation (Walker 27/3/1):
    - 3 Orbit Planes with 9 Satellites each
    - Altitude: 23616 km
    - Inclination: 56°
    - Ground Track repeating every 10 siderial days
  - GLONASS Constellation (Nominal Constellation)
    - 3 Orbit Planes with 8 Satellites each
    - Altitude: 19100 km
    - Inclination: 64.8°
    - Ground Track repeating every 8 siderial days

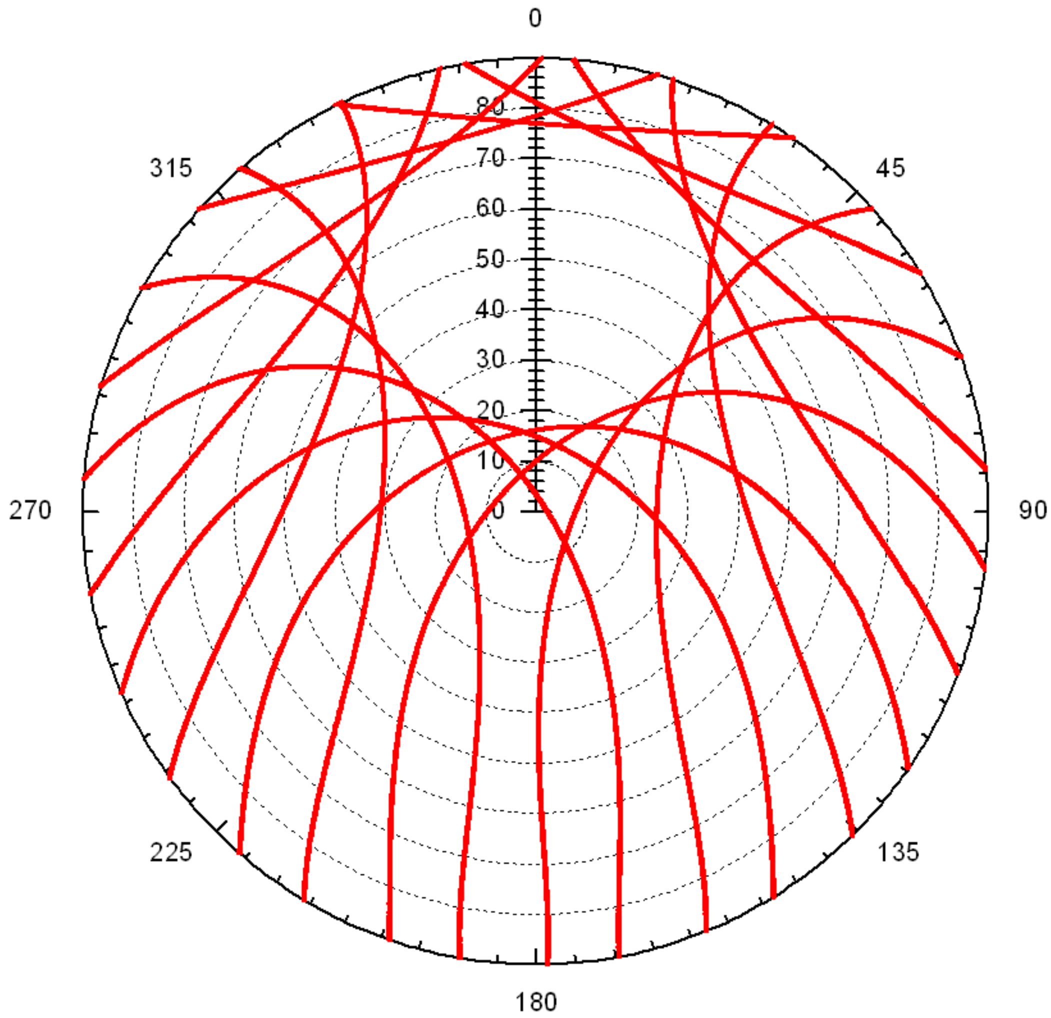
GPS Sky-Plot for Hannover 2006-06-14



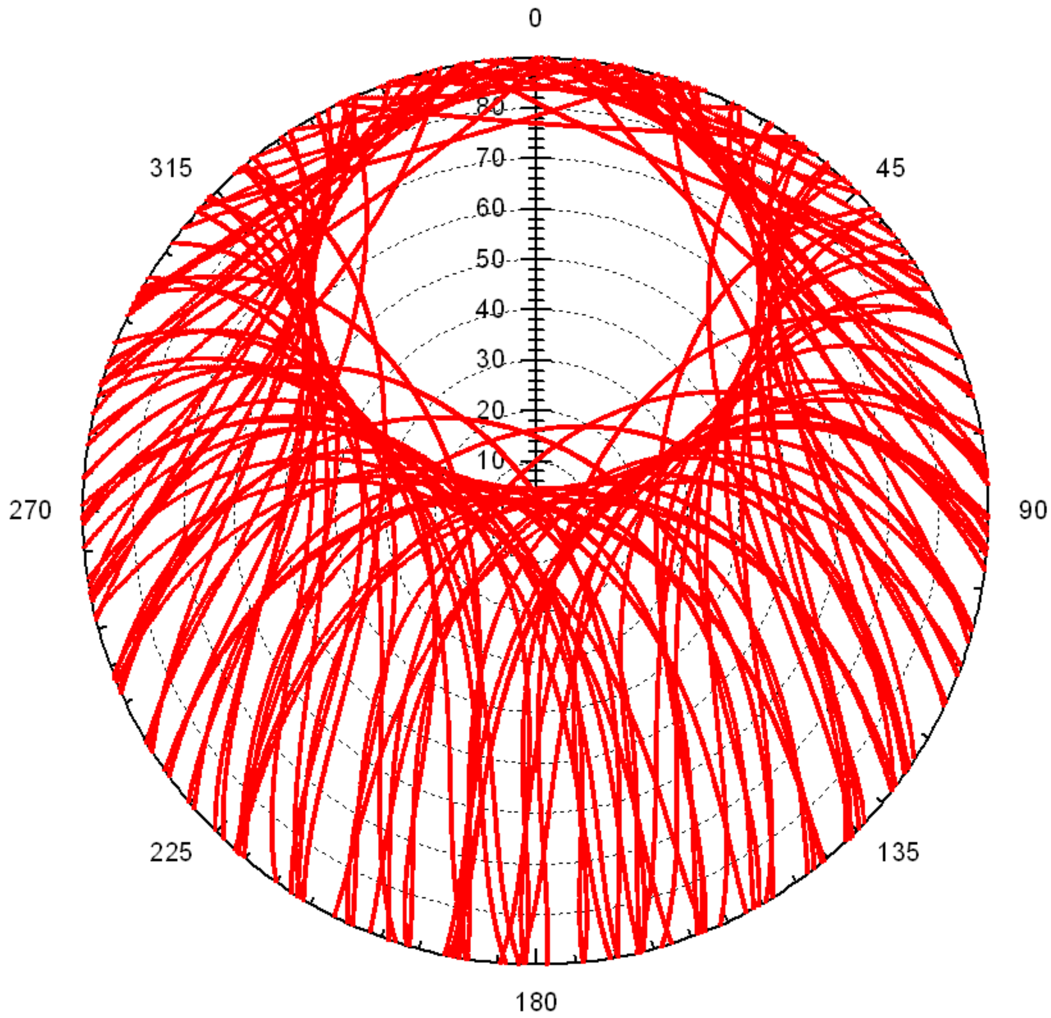
Galileo Sky-Plot for Hannover 2006-06-14



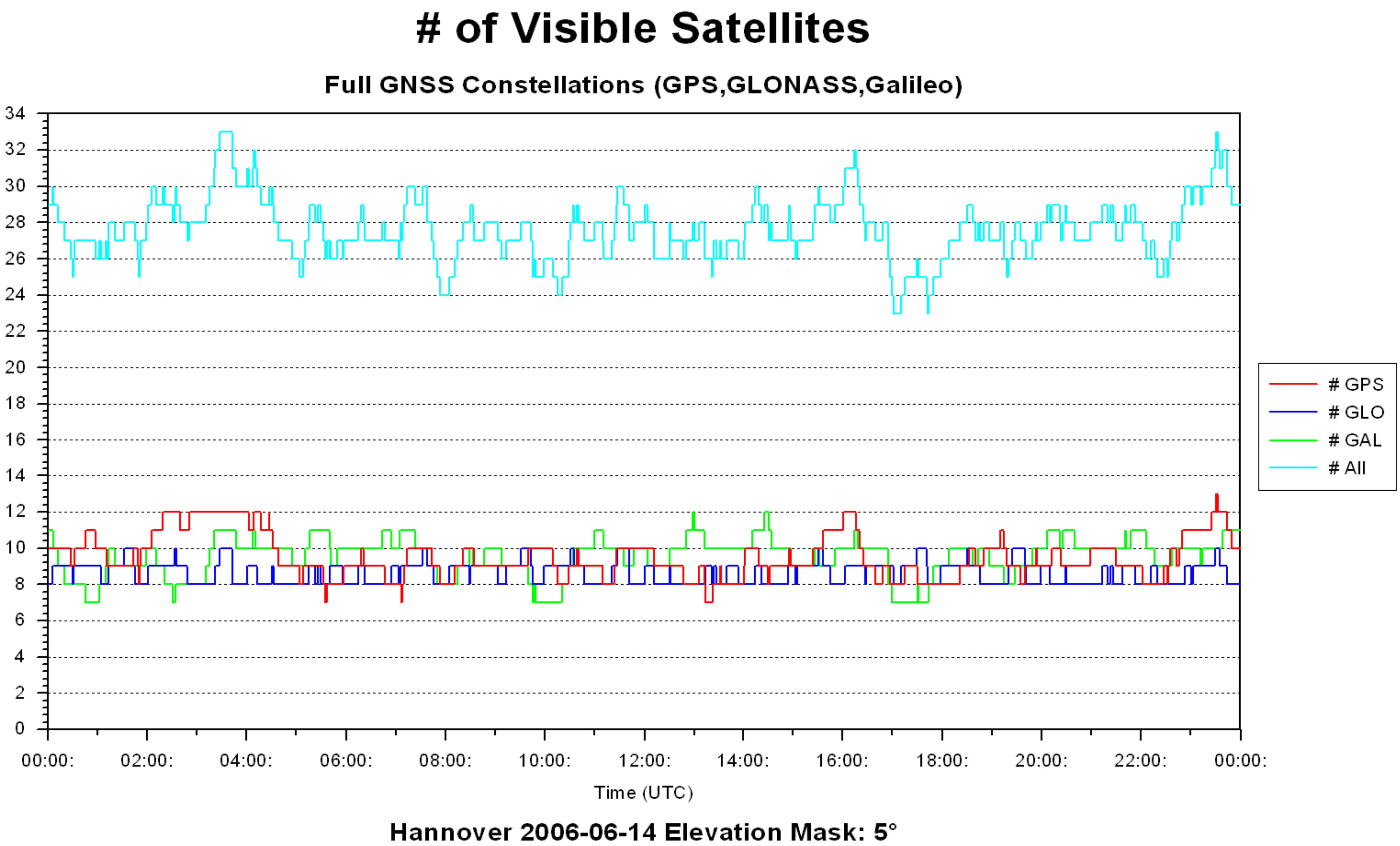
GLONASS Sky-Plot for Hannover 2006-06-14



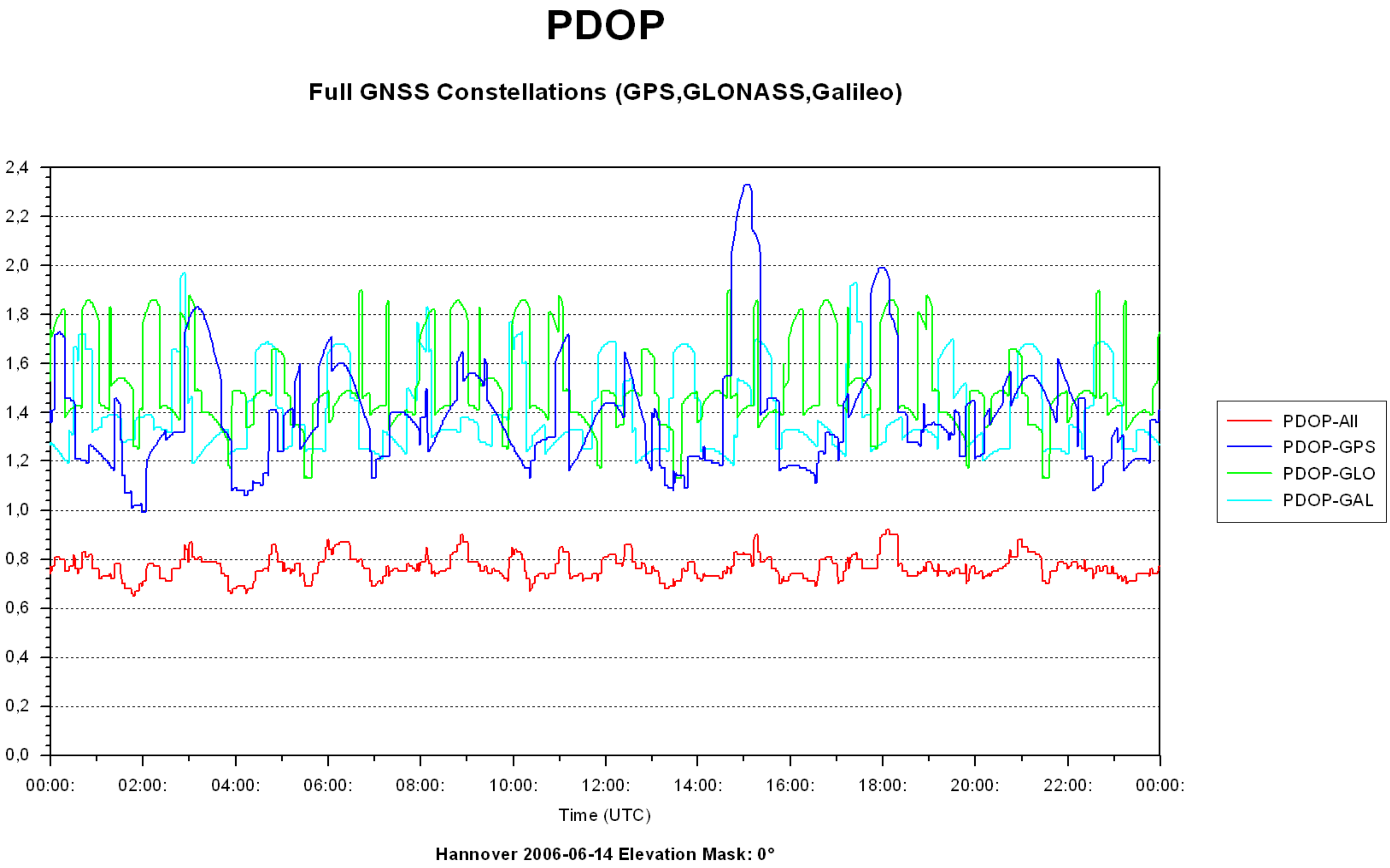
GNSS Sky-Plot for Hannover 2006-06-14



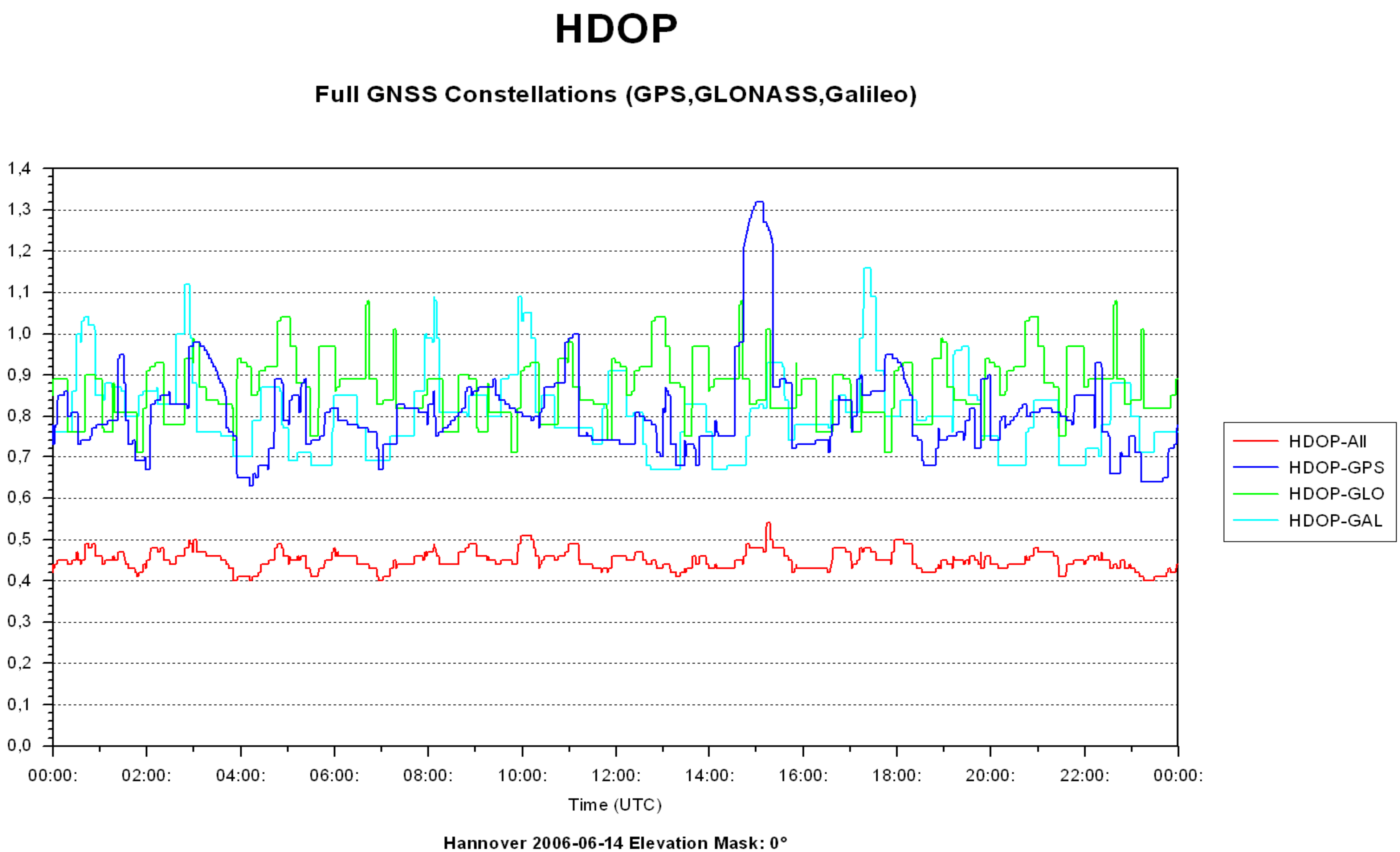
GNSS Visible Satellites for Hannover 2006-06-14



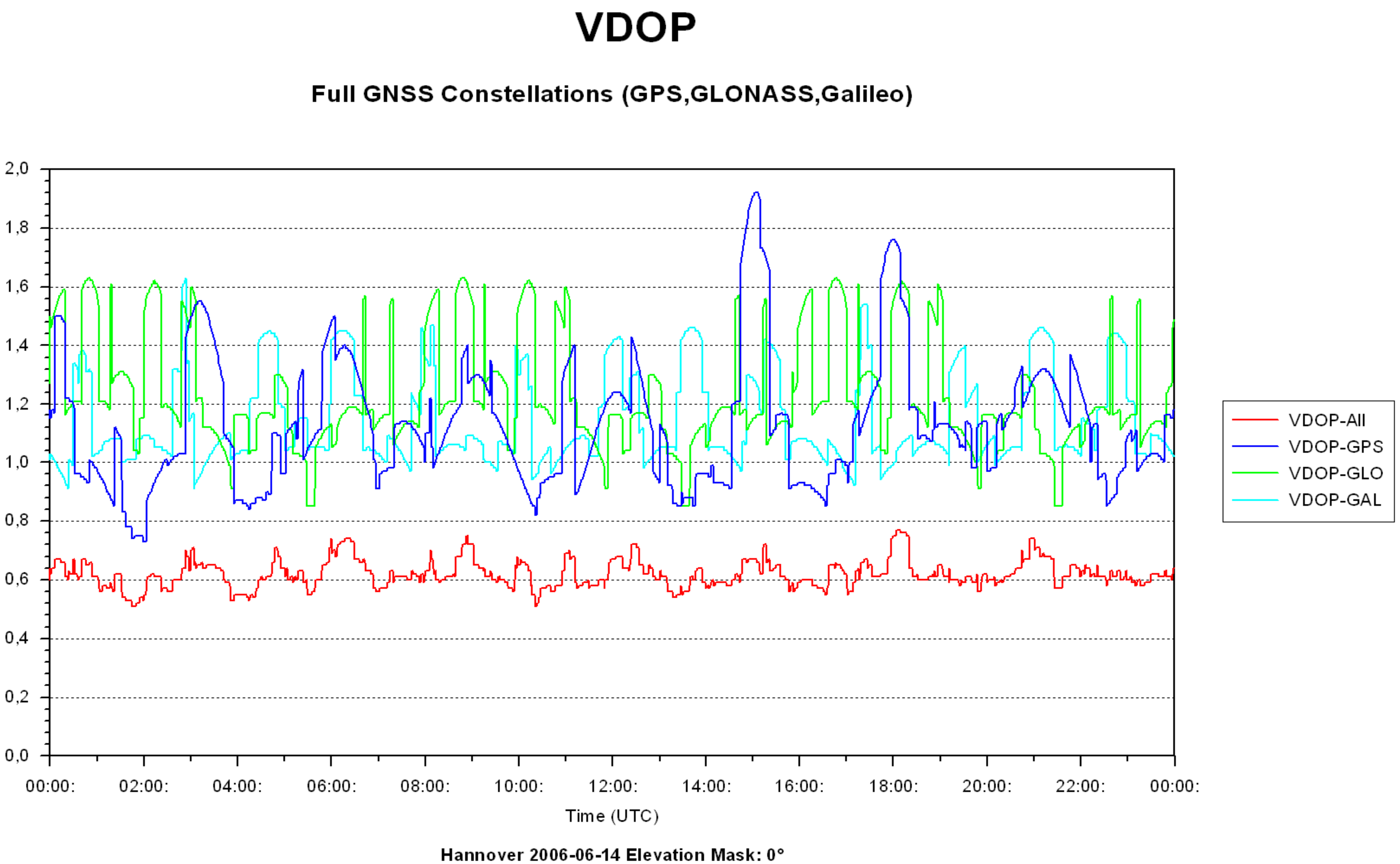
GNSS PDOP for Hannover 2006-06-14



GNSS HDOP for Hannover 2006-06-14

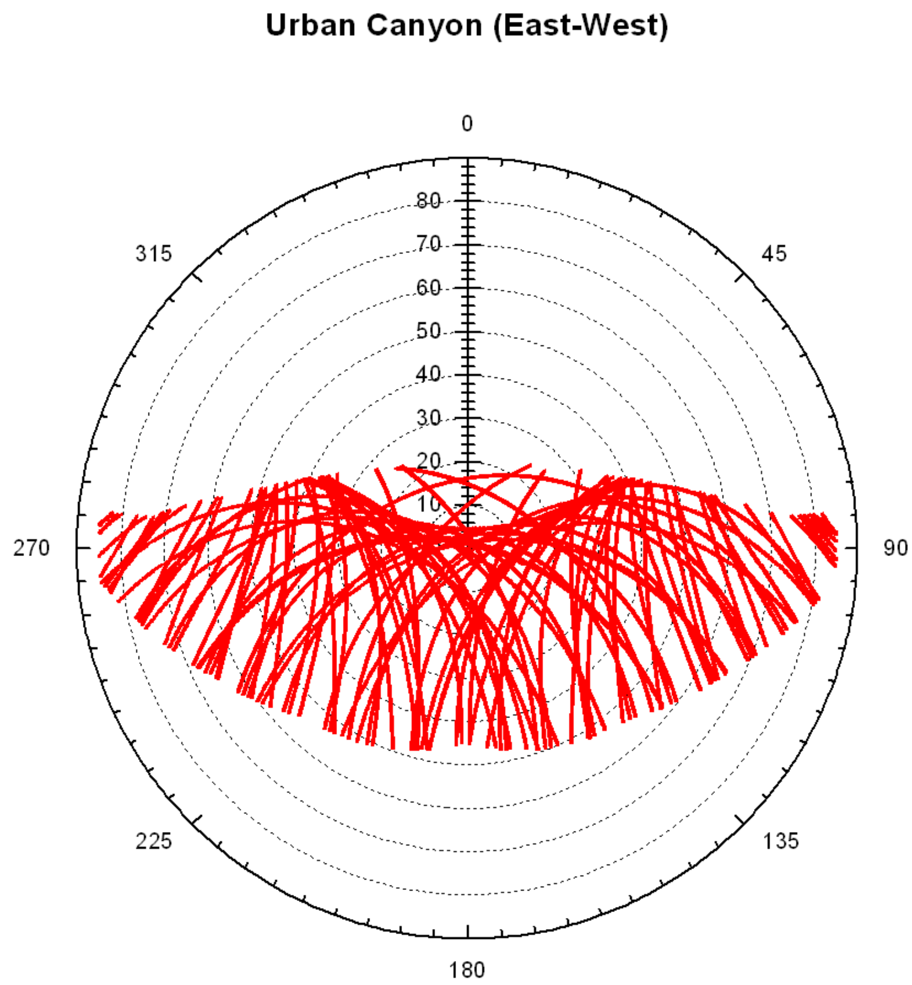


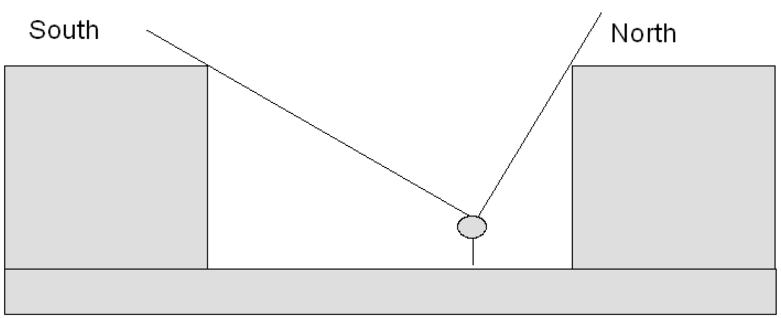
GNSS VDOP for Hannover 2006-06-14



GNSS Improvement of Availability in Obstructed Areas

Obstructions





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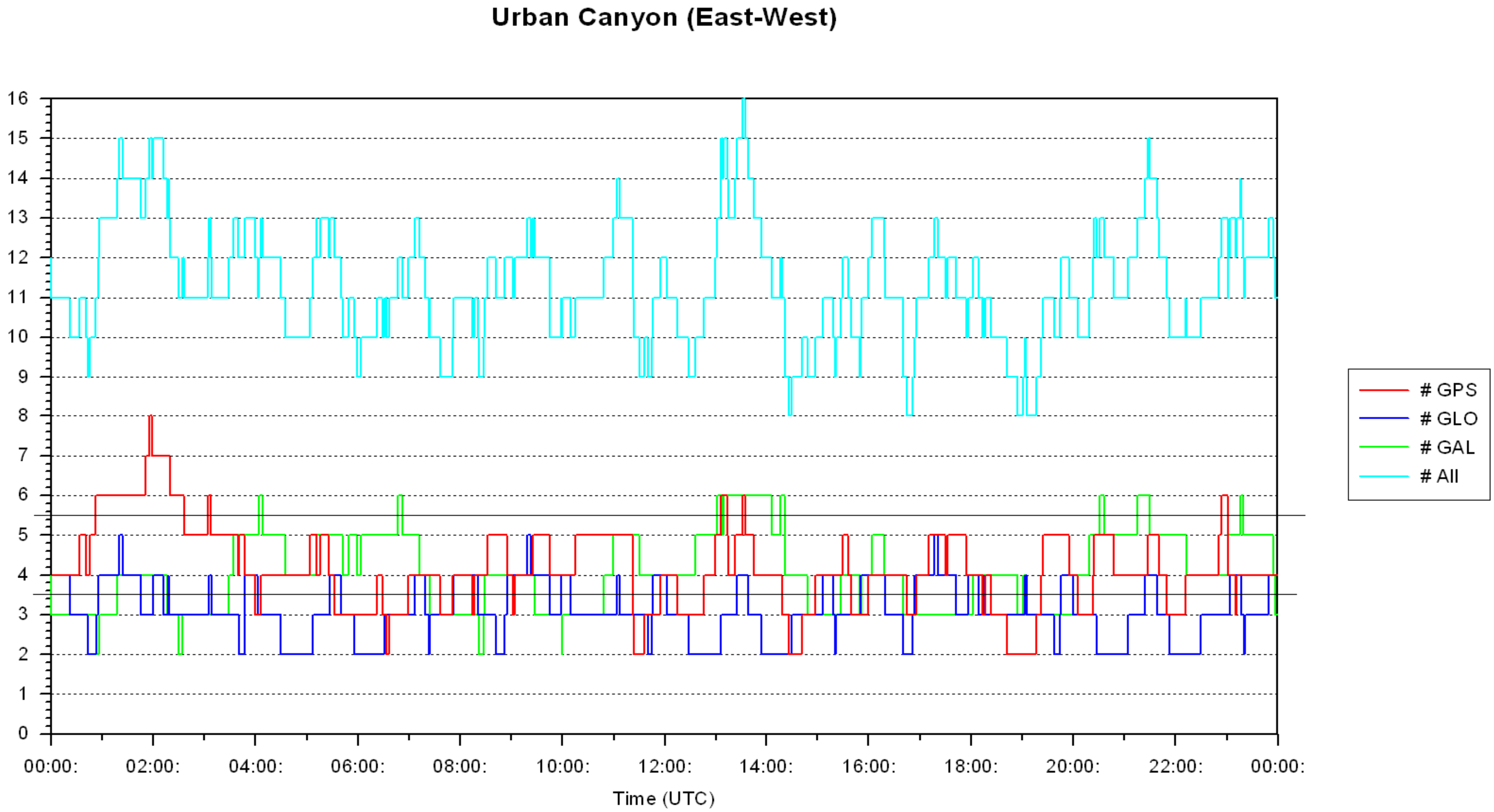

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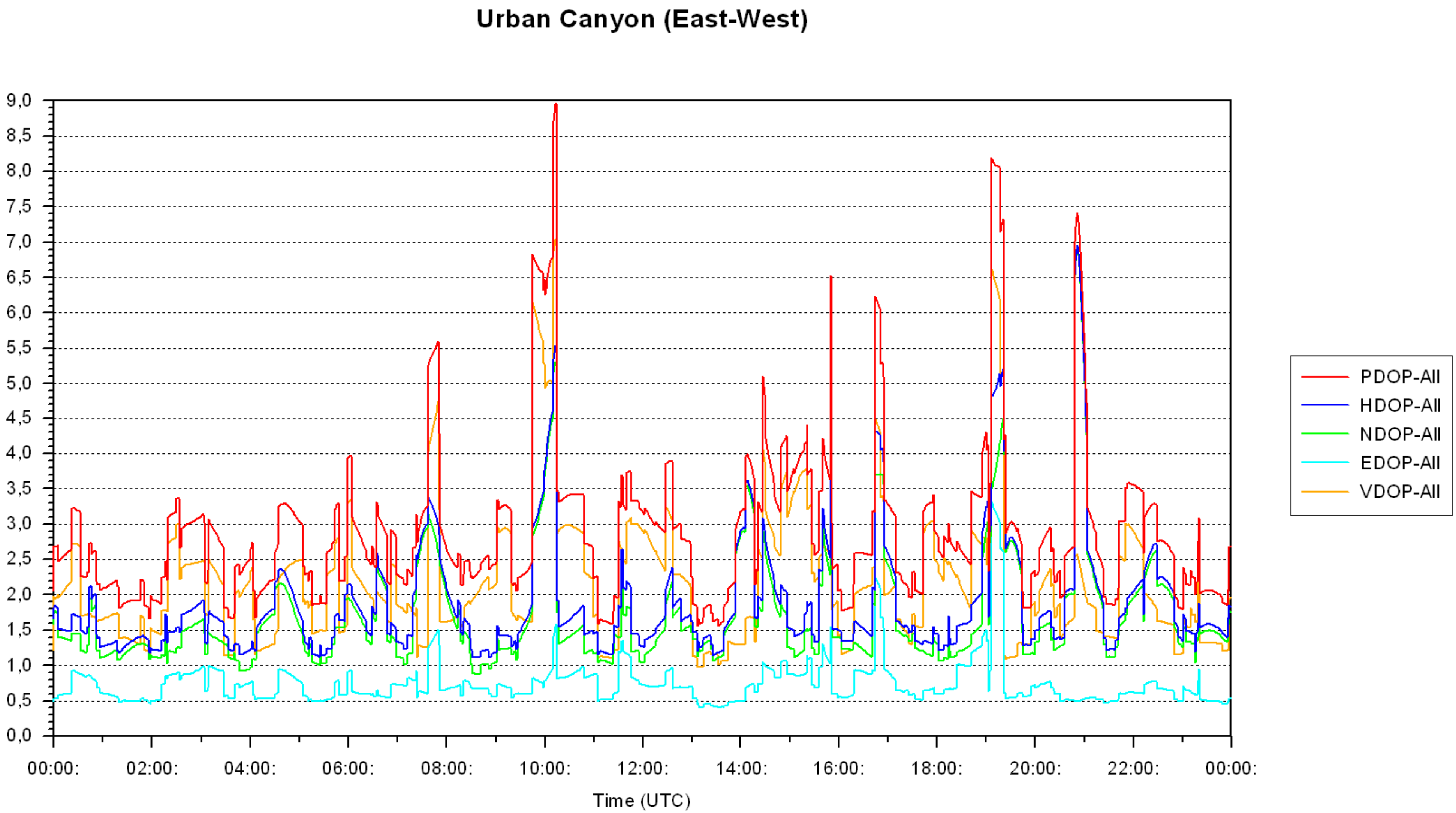

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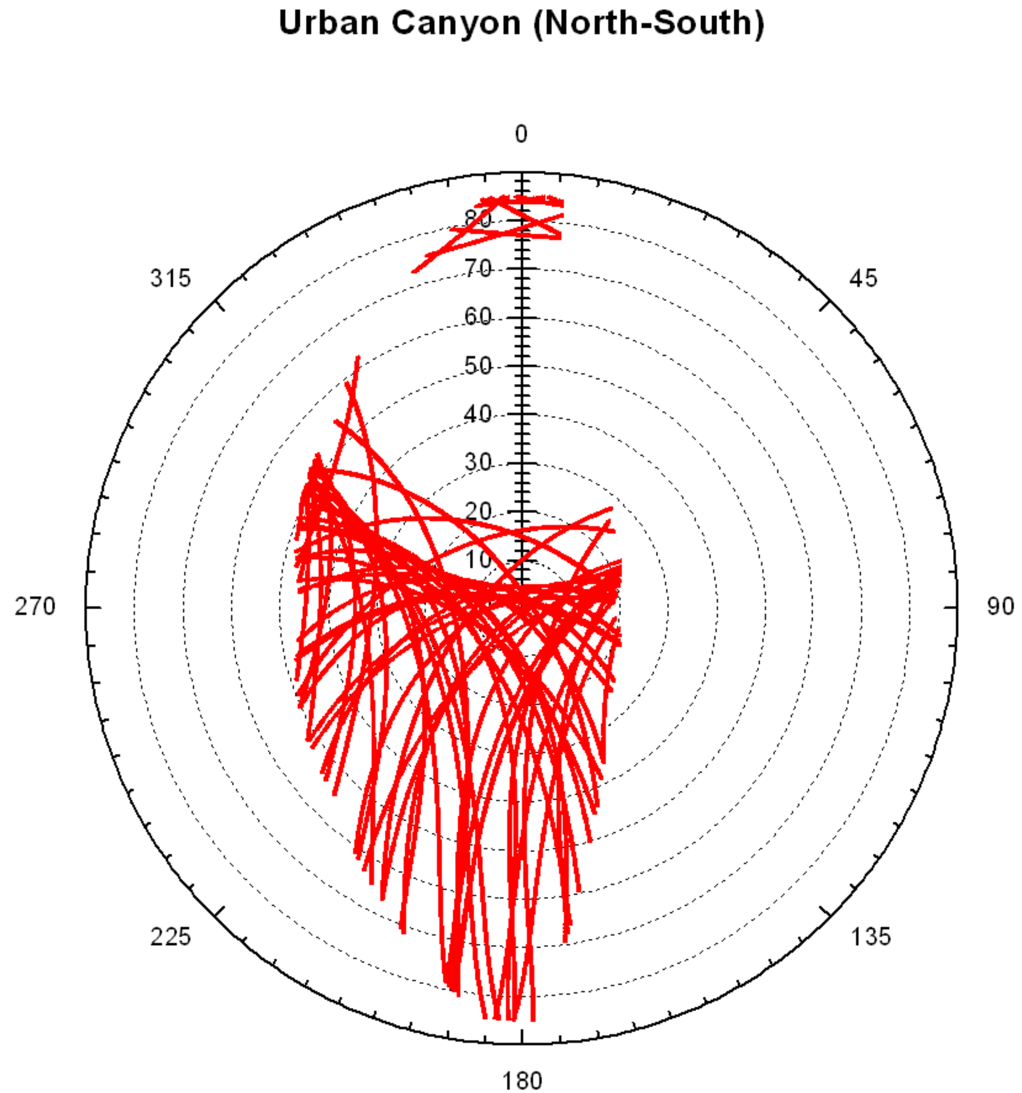

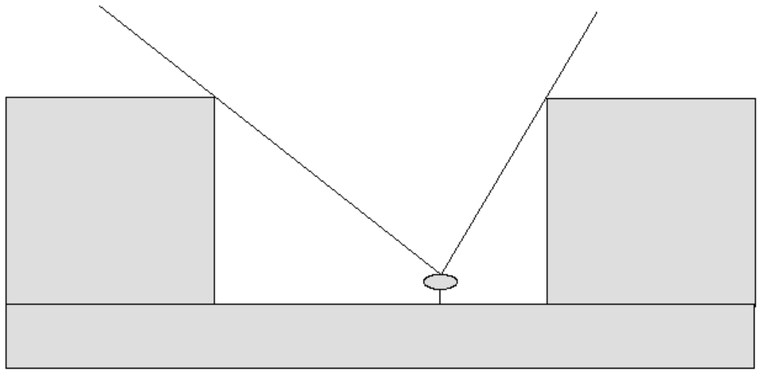

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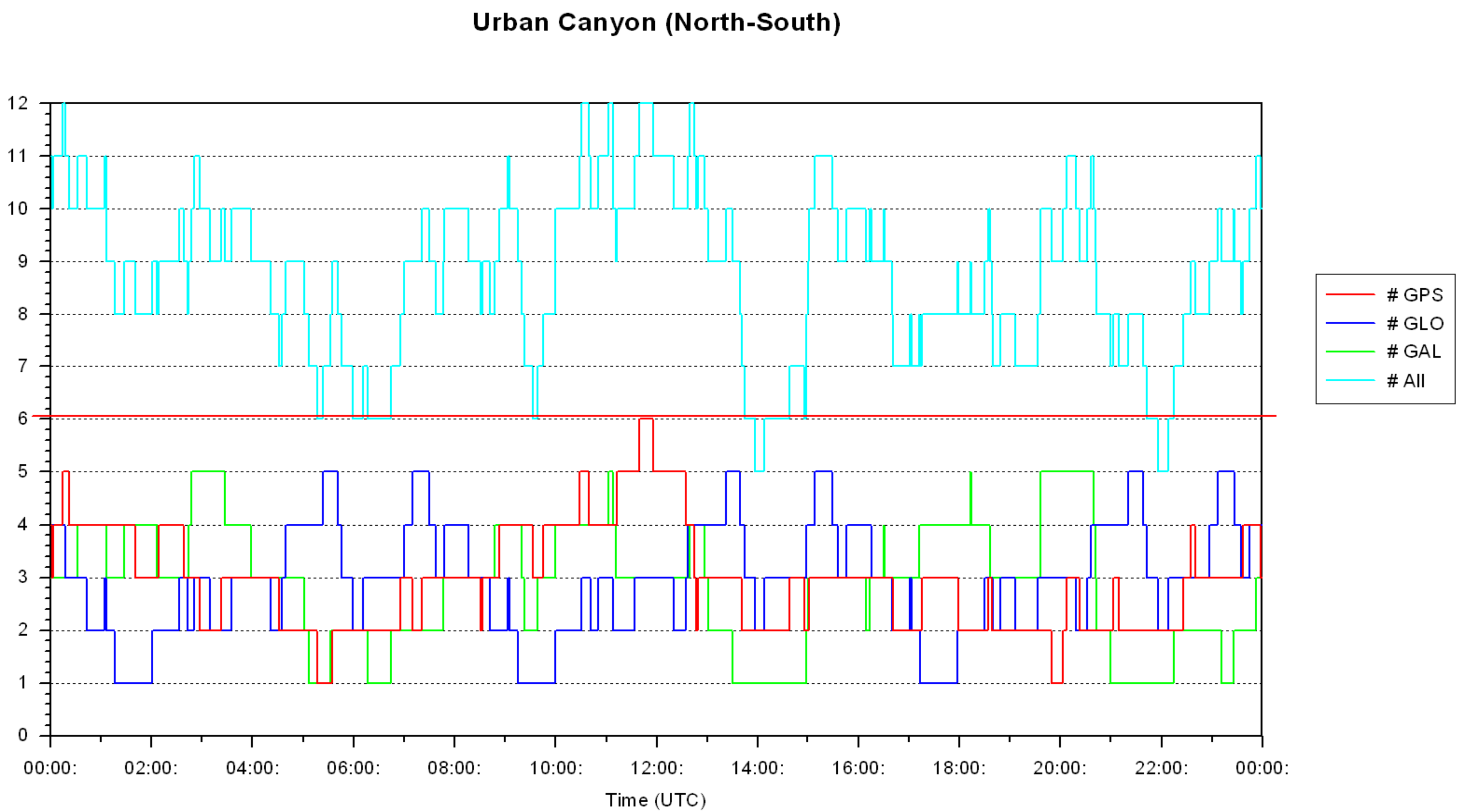

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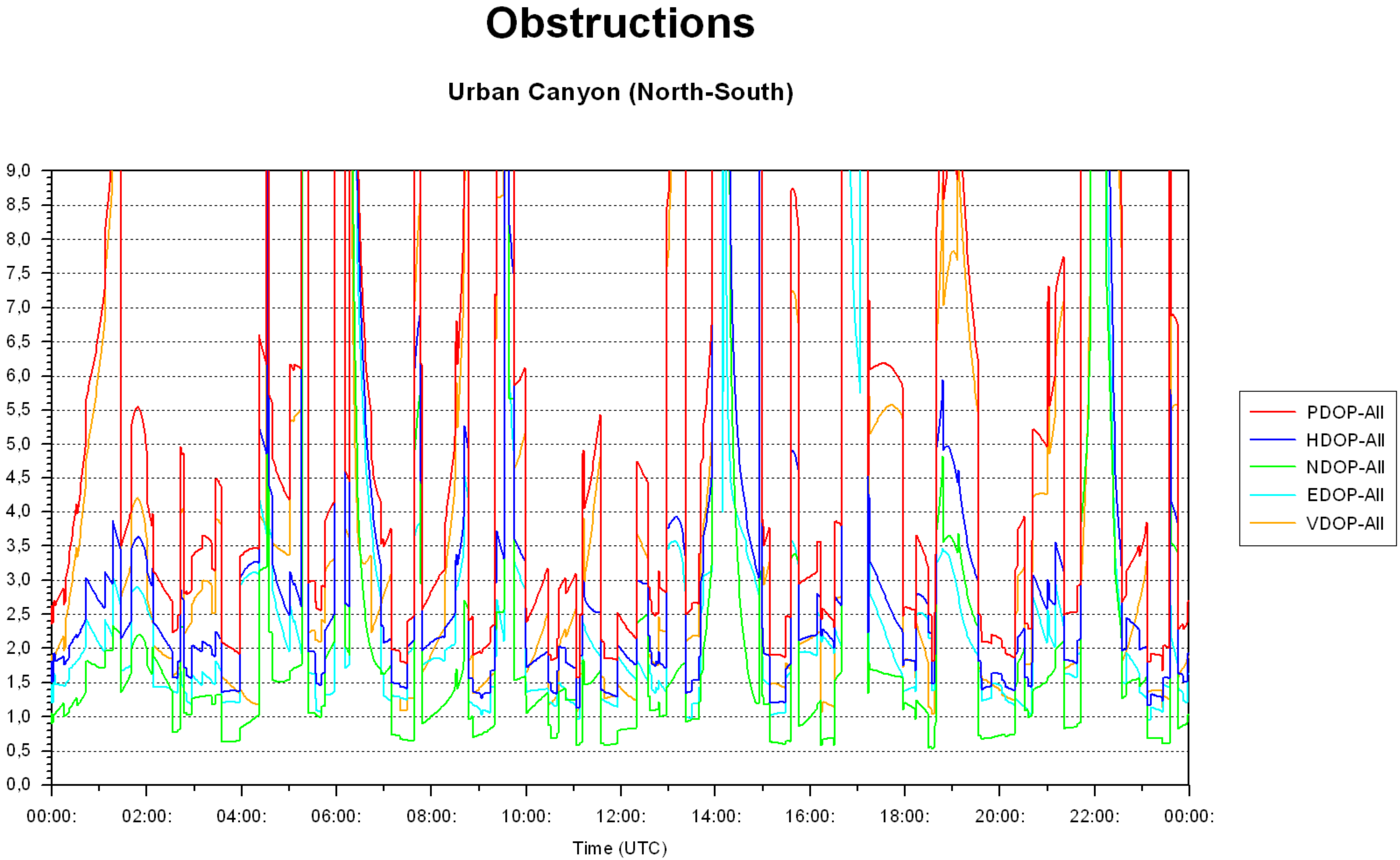


New Signals and Ambiguity Resolution

- 3rd GPS Frequency (L5)
- Up to 5 Galileo Frequencies
- New Codes (L2C, L1C?, Galileo) with improved Accuracy
  - Code Noise Level in the order of 10 cm or better
  - Reduced Multipath Errors
- New Carrier and Code Phase Linear Combinations with 3 and more Frequencies
- Literature indicates (very) Optimistic Ambiguity Resolution Performance
  - TCAR
  - MCAR
  - ...

Linear Combinations of Carrier Phases

- Linear Combination with Integer Coefficients (n,m,k,...)
- $$\Phi_{n,m,k,\ldots} = n*\Phi_1 + m*\Phi_2 + k*\Phi_3 \ldots$$
- Apparent Frequency:
- $$f_{n,m,k,\ldots} = n*f_1 + m*f_2 + k*f_3 \ldots$$
- Apparent Wavelength:
- $$\lambda_{n,m,k,\ldots} = \frac{c}{f_{n,m,k,\ldots}}$$
- Ionospheric Influence relative to L1

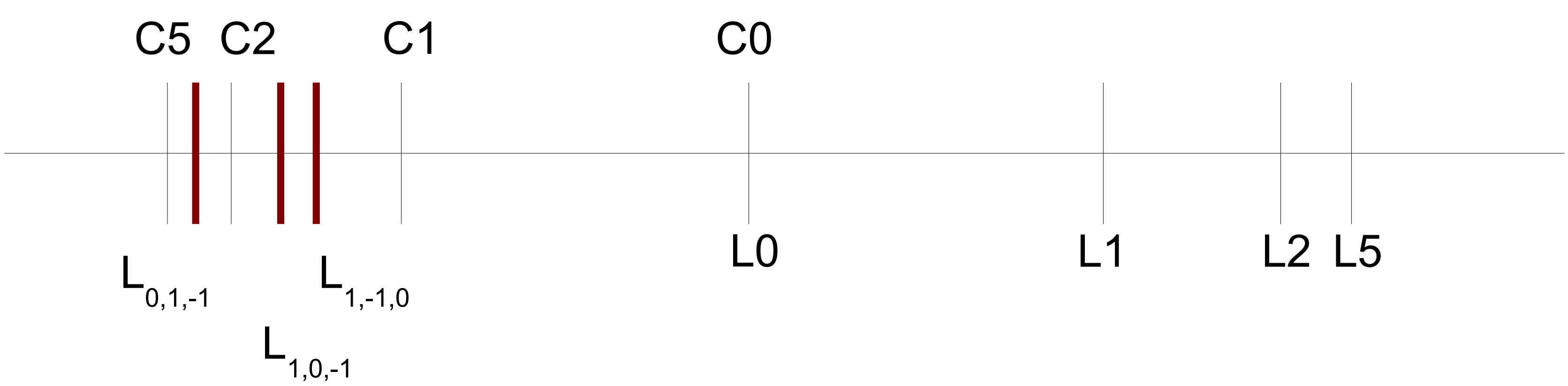
$$dI_{n,m,k,\ldots} = \frac{\frac{n}{f_1} + \frac{m}{f_2} + \frac{k}{f_3} + \ldots}{n*f_1 + m*f_2 + k*f_3 + \ldots} * f_1^2 * dI_1$$

Linear Combinations of Carrier Phases

- Ionospheric Amplification Factor
-
- $$vI_{n,m,k,\ldots} = \frac{\frac{n}{f_1} + \frac{m}{f_2} + \frac{k}{f_3} + \ldots}{n * f_1 + m * f_2 + k * f_3 + \ldots} * f_1^2$$
-
- Noise: Phase Noise s [radians]
- $$s_{n,m,k,\ldots} = \sqrt{(n*n + m*m + k*k + \ldots)} * s$$
- Caution: Amplification of Biases
  - MP (Near Field, Far Field)
  - Antenna
  - Keep n,mk, small

Some GPS Linear Combinations

L1	L2	L5	Lambda	VI1	VI/Lambda	Sigma	Sigma-Cyc
1	0	0	0.1903	1.0000	5.2550	0.0009	0.0048
0	1	0	0.2442	1.6469	6.7440	0.0012	0.0048
0	0	1	0.2548	1.7933	7.0372	0.0012	0.0048
1	-1	0	0.8619	-1.2833	-1.4889	0.0058	0.0068
0	1	-1	5.8610	-1.7186	-0.2932	0.0396	0.0068
1	0	-1	0.7514	-1.3391	-1.7821	0.0051	0.0068
1	-5	4	2.0932	-0.6616	-0.3161	0.0648	0.0309
1	-4	3	1.5424	-0.9397	-0.6093	0.0376	0.0243
1	-3	2	1.2211	-1.1020	-0.9025	0.0218	0.0179
1	-2	1	1.0105	-1.2083	-1.1957	0.0118	0.0117



Some Galileo Linear Combinations

L1	E5a	E5b	E5	E6	Lambda	VI1	VI/Lambda	Sigma	Sigma-Cyc
1	0	0	0	0	0.1903	1.0000	5.2550	0.0009	0.0048
0	1	0	0	0	0.2548	1.7933	7.0372	0.0012	0.0048
0	0	1	0	0	0.2483	1.7032	6.8583	0.0012	0.0048
0	0	0	1	0	0.2515	1.7474	6.9466	0.0012	0.0048
0	0	0	0	1	0.2344	1.5178	6.4742	0.0011	0.0048
1	-1	0	0	0	0.7514	-1.3391	-1.7821	0.0051	0.0068
1	0	-1	0	0	0.8140	-1.3051	-1.6032	0.0055	0.0068
1	0	0	-1	0	0.7815	-1.3219	-1.6915	0.0053	0.0068
1	0	0	0	-1	1.0105	-1.2320	-1.2192	0.0068	0.0068
0	1	-1	0	0	9.7684	-1.7477	-0.1789	0.0660	0.0068
0	1	0	-1	0	19.5368	-1.7702	-0.0906	0.1319	0.0068
0	1	0	0	-1	2.9305	-1.6498	-0.5630	0.0198	0.0068
0	0	1	-1	0	19.5368	-1.7252	-0.0883	0.1319	0.0068
0	0	1	0	-1	4.1865	-1.6079	-0.3841	0.0283	0.0068
0	0	0	1	-1	3.4477	-1.6286	-0.4724	0.0233	0.0068
0	2	-3	0	1	29.3052	-0.7690	-0.0262	0.5235	0.0179
0	4	-1	-4	1	29.3052	-0.6340	-0.0216	0.8159	0.0278
1	-1	1	3	-4	4.5085	0.0858	0.0190	0.1139	0.0253
1	4	1	-3	-3	3.9074	-0.0012	-0.0003	0.1119	0.0286
3	-5	0	0	3	0.1119	0.0002	0.0018	0.0035	0.0313
3	-3	2	-4	3	0.1119	0.0007	0.0064	0.0037	0.0327
4	-3	-1	1	0	0.1087	-0.0003	-0.0031	0.0027	0.0248

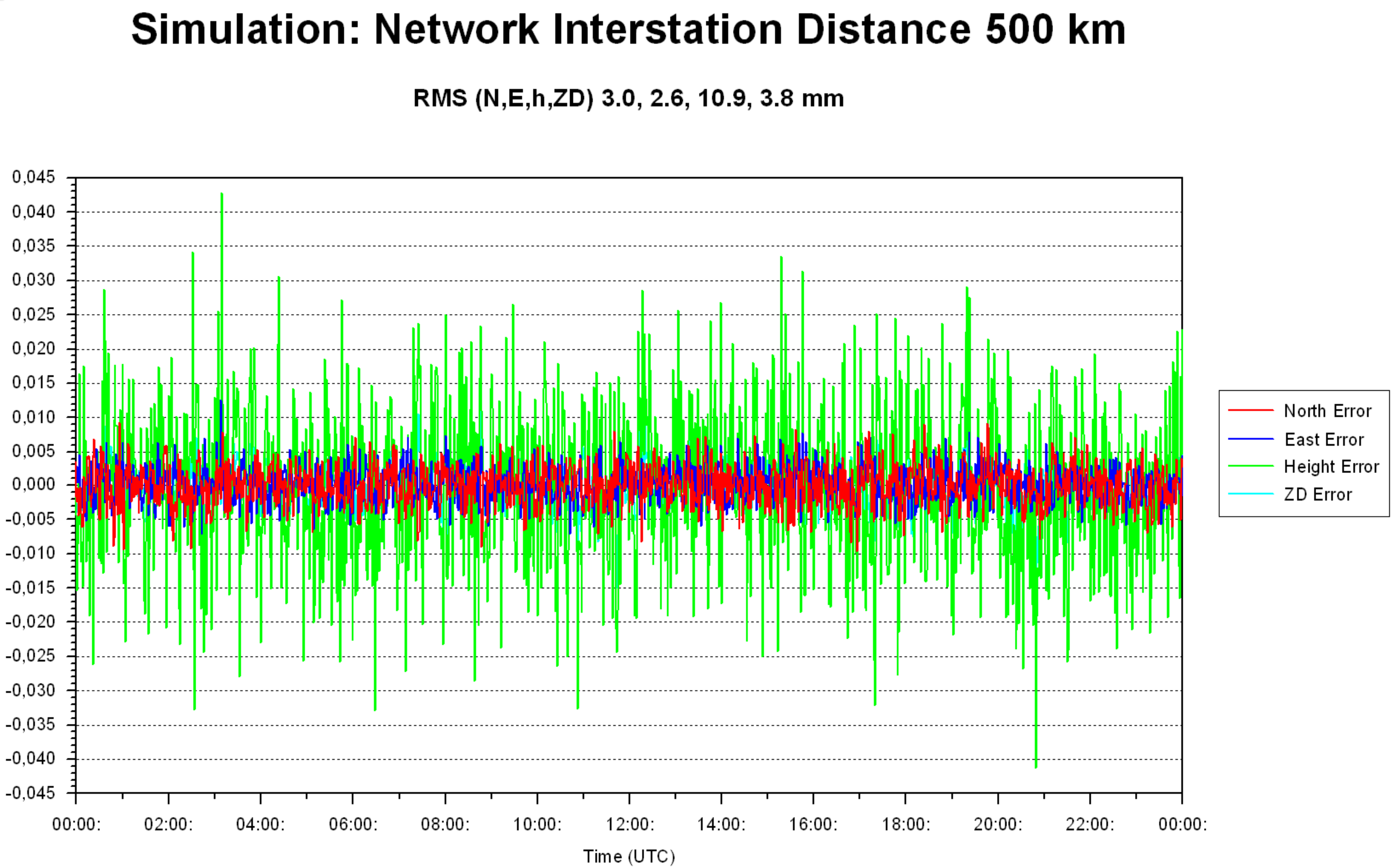
Simulations

- 2 Scenarios
  - 500 km Interstation Distances within Network
    - Residual Troposphere for Rover Position 2 cm RMS ZD
    - Residual Ionosphere 0.6 m RMS per Satellite
  - 100 km Interstation Distances within Network
    - Residual Troposphere for Rover Position 2 mm RMS ZD
    - Residual Ionosphere 0.2 m RMS per Satellite
  - 3 Frequency GPS
  - 3 Frequency Galileo (L1, E6, E5a+b)
  - 2 Frequency GLONASS
  - Code Noise 0.4 m, Code MP 2 m RMS, 60 s Correlation Length
  - Phase Noise 0.002 m, Phase MP 0.004 m RMS, 60 s Cor.Length

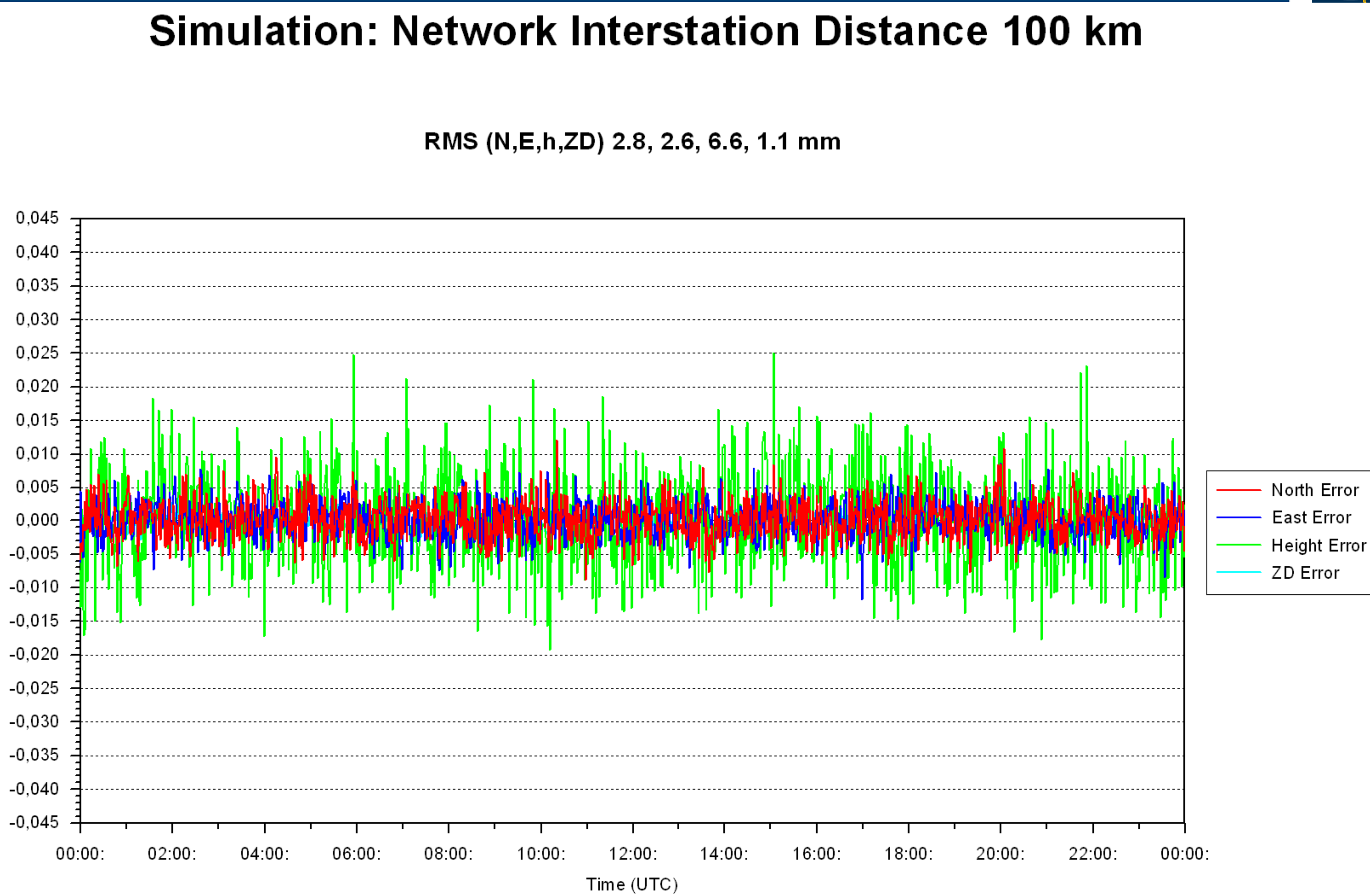
Simulations

- Overall Results (both Networks)
  - Instantaneous Ambiguity Fixing >90%
  - Fixing within 20 s: 100%

Accuracy (Sparse Network 500 km)



Accuracy (Network 100 km)



Do we still need RTK Networks with full GNSS Constellations

- Answer: YES
  - Height Accuracy
  - Support for Rovers with Single / Dual Frequency Receivers
  - Support for Rovers in Areas with Obstructions
  - Redundancy
- Network Density may be Reduced
  - Rovers should estimate Residual Troposphere

Challenges for RTK Networks and Network RTK Software

- Non-Homogeneous Reference Stations / Satellites
  - Receivers with different capabilities of Signal Tracking
  - Satellites with different Signals (GPS)
- Network should support as many signals as possible
  - Serve all Rovers
- Software must be flexible (mixed Receivers/Satellites/Signals)
- Representation of Error Sources should switch
  - From Observation Space Representation (OSR) (RTCM)
  - To State Space Representation (SSR)
  - > Reduction of Bandwidth
  - > Support for all Signals

Challenges for Network RTK Software and RTK Networks

- Rigorous Network Adjustment Requires State Parameters:
  - Satellite Orbits (3 or 6 per Satellite)
  - Satellite Clocks (2 or 3 per Satellite)
  - Satellite Signal Biases (2 per Satellite per Signal – 1)
  - Ionosphere (adquate Model + #Rx * #Sv)
  - Troposphere (1 or 2 per Receíver)
  - Receiver Signal Biases+Clock (2 per Signal -1 +1)
  - Receiver Coordinates (3)
  - Carrier Phase Ambiguities (1*RCVs*SATs*Signals)
  - ==> 30 Stations, 30 Satellites, 3 Signals/Satellite (Mean)
  - ==> (14*30 + 100 + 60 + 90 + 90 + 3600 = **4360 Parameters**)
  - ==> Improved Filter Algortihms Required!

Summary

- Full GNSS Constellations Provide
  - Improved Availability
  - Improved Accuracy
  - Fast Ambiguity Fixing over longer Distances using new Signals and high number of Satellites
- RTK Networks will still be necessary
- Complexity of Network Setup and Software will increase

Thank you for your attention!